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TOWARDS A COMPARISON OF SPACEBORNE AND GROUND-BASED SPECTRODIRECTIONAL REFLECTANCE DATA

J. Schopfer⁽¹⁾, S. Huber⁽¹⁾, D. Odermatt⁽¹⁾, T. Schneider⁽²⁾, W. Dorigo⁽³⁾, N. Oppelt⁽⁴⁾, B. Koetz⁽¹⁾, M. Kneubuehler⁽¹⁾, K.I. Itten⁽¹⁾

⁽¹⁾ Remote Sensing Laboratories (RSL), Dept. of Geography, University of Zurich, Winterthurerstr. 190, CH-8057 Zurich, Switzerland, Email: jschopfer(shuber, dodermat, bkoetz, kneub, itten)@geo.unizh.ch

⁽²⁾ Limnological Research Station, TU Munich, Hofmark 1-3, D-82393 Iffeldorf, Email: tomi.schneider@lrz.tu-muenchen.de

⁽³⁾ DLR/DFD Oberpfaffenhofen, D-82234 Wessling, Email: Wouter.Dorigo@dlr.de

⁽⁴⁾ Dept. for Earth and Environmental Sciences, Section Geography, University of Munich, Luisenstr. 37, D-80333 Munich, Email: n.oppelt@iggf.geo.uni-muenchen.de

ABSTRACT

Almost all natural surfaces exhibit an individual anisotropic reflectance behaviour due to the contrast between the optical properties of surface elements and background and the geometric surface properties of the observed scene. The resulting bidirectional effects are present in all reflectance data and thus occur as well in various vegetation indices (VI's) retrieved from multiangular data. No matter whether these effects are considered as noise or as a source of additional information, accurate knowledge about their magnitude is important.

This preliminary study is based on data of the spaceborne ESA-mission CHRIS (Compact High Resolution Imaging Spectrometer) onboard PROBA-1 and on ground-based spectrodirectional measurements performed with the dual view field goniometer system FIGOS. The objectives of this study are focused on directional effects in CHRIS and FIGOS reflectance data of a Triticale field as well as on the variability of retrieved vegetation indices for selected view angles in both multiangular datasets.

1. INTRODUCTION

Multiangular measurements provide the potential of a more accurate assessment of the specific reflectance characteristic of selected targets. The contrast between the optical properties of surface elements and background and the geometric surface properties of the observed scene lead to individual anisotropic reflectance characteristics for the respective targets. The underlying concept which describes the reflectance characteristic of a specific target area is called the bidirectional reflectance distribution function (BRDF) and depends on the illumination and observation directions. Consequently, directional effects are present in all reflectance data and thus occur as well in various vegetation indices (VI's) retrieved from multiangular data, as various studies have demonstrated [1-3]. Such effects can be considered as noise or as a source of

additional information, but in any case accurate knowledge about their magnitude and variability is important. However, for many recently developed narrowband indices this is often unknown [1]. Typically, nadir reflectance measurements are used for deriving VI's or empirical and physical correction approaches are developed to deal with the influence of angular effects [4-6]. In contrast, one way to profit from multiangular data is described by Gemmell et al. [7] who showed that off-nadir viewing improved specific indices performance for discriminating e.g. fractional cover and leaf area index (LAI).

The objectives of this study are focused (1) on the comparison between hemispherical conical reflectance factors (HCRF) of CHRIS and ground-based goniometric data and (2) on the variability of selected vegetation indices for corresponding view angles in both multiangular datasets. Directional effects are investigated for the Normalized Difference Vegetation Index (NDVI) [8] and the Photochemical Reflectance Index (PRI) [9], respectively.

2. DATA ACQUISITION

The data for this study were acquired in summer 2006 in the framework of an extensive field campaign [10]. The study site Gilching (48°05' N, 11°17' E) is located close to the airport Oberpfaffenhofen, Germany, at an altitude of approx. 600-700 meters asl. Subsequent investigations were carried out using ground-based spectrodirectional goniometer measurements and mode 5 data of the spaceborne ESA-mission CHRIS (Compact High Resolution Imaging Spectrometer) onboard PROBA-1 [11].

2.1. Target area

The respective field under observation was a flat vegetation area of 200m x 500m and consisted of man-made Triticale, a hybrid between rye and wheat. At measurement time it showed a height of about 90cm with 10 – 20cm spacing among the single plants. Fig. 1

shows the Triticale in a nadir view from the goniometer and a lateral view, respectively.



Figure 1. Lateral view (left) and nadir view (right) of Triticale.

2.2. CHRIS data acquisition and processing

CHRIS simultaneously supplies five viewing angles with the nominal fly by zenith angles (FZA's) at $\pm 55^\circ$, $\pm 36^\circ$ and 0° (nadir) in 37 bands (mode 5, 447nm to 1035nm) with a spatial resolution of 18m. Unfortunately, only 3 images were acquired at nominal FZA's of $\pm 36^\circ$ and nadir on June 21, 2006, over the study site Gilching. The images covered an area of 7 km x 13 km.

The actual viewing zenith angles of CHRIS data acquisition do rarely represent the nominal FZA's due to uncertainties in pointing. Fig. 2 shows the actual view angles for the 3 images. It can also clearly be seen that the acquisition has not occurred in the solar principal plane.

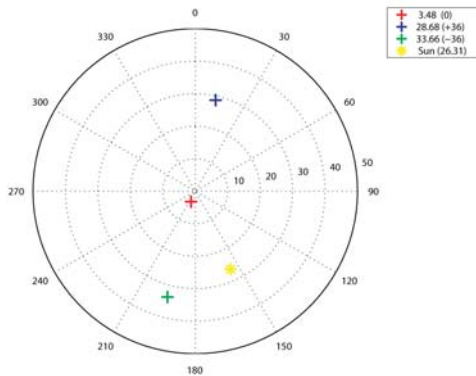


Figure 2. Acquisition geometries and illumination angles for the 3 CHRIS images. The nominal fly-by zenith angles are listed in brackets and the center of the plot represents the target.

The three CHRIS multiangular acquisitions were orthorectified using a 3D physical model [12, 13] and a SRTM derived digital elevation model (DEM) resampled to 18m using bilinear interpolation [14]. The resulting RMSE's derived from Ground Control Points (GCP's) were at 0.66 – 0.86 pixel along track and 0.58 –

0.75 pixel across track. Subsequent atmospheric correction of the CHRIS radiance data was performed using ATCOR-3 [15], which is based on MODTRAN-4. ATCOR-3 enables the processing of data from tilted sensors by accounting for varying path lengths through the atmosphere, varying transmittance and for terrain effects by incorporating digital terrain model (DTM) data and their derivatives such as slope and aspect, sky view factor and cast shadow.

2.3. Ground-based data acquisition

During this study the dual FOV goniometer system FIGOS was used for the first time in its updated dual view configuration [16]. The dual FOV FIGOS simultaneously measures reflected and incoming diffuse radiances at the same angular (azimuth steps of 30° , zenith steps of 15°) and spectral resolution. Spectralon references are collected in the beginning and in the end of each hemisphere as well as at every nadir bypass with the downward looking sensor. Fig. 3 shows the goniometer setup for the respective target of interest.



Figure 3. Dual FOV FIGOS setup for acquiring spectrodirectional ground truth data. The goniometer had to be raised by 80cm to assure a constant observation distance for all view angles.

Spectrodirectional measurements are performed using two ASD FieldSpec 3 covering a spectral range from 350nm to 2500nm. Data is sampled at intervals of 1.4nm (350 – 1050nm) and 2nm (1000 – 2500nm) with a spectral resolution of 3nm at 700nm and 10nm at 1400/2100nm, respectively [17]. Since the instantaneous field-of-view is 3° and always pointing to the centre of the hemisphere (downward looking optic), the corresponding ground instant field-of-view (GIFOV) is circular with 10.5cm (diameter) in nadir direction. However, for large off-nadir observation angles the sensor's footprint becomes elliptical with a maximum longitudinal extent of 41cm.

Simultaneously, an MFR-7 shadowband sunphotometer was used to directly record the total and diffuse illumination in 7 bands (broadband, 415, 500, 615, 673, 870 and 940nm). The direct sun radiance is then

calculated as a difference of the two, taking the respective sun zenith angle into account.

In total seven goniometer datasets were acquired on June 22 and June 24, 2006, over the same target area. The goniometer dataset no. 4 was obtained on June 24 under low atmospheric influence and at a similar sun zenith angle as CHRIS data acquisition took place. It is therefore preferential for comparison analysis on HCRF level. Fig. 4 shows an overview of the goniometer datasets incorporating the corresponding illumination variability.

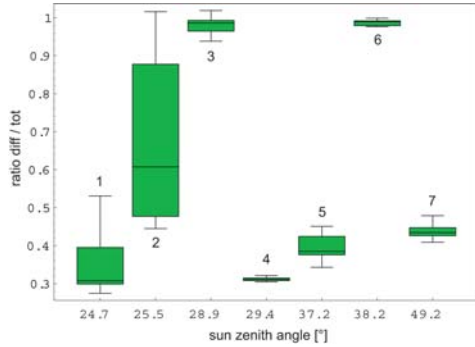


Figure 4. Variability of the ratio of diffuse/total radiation during corresponding goniometer measurements. Data are represented as box plots where the boxes show 50% of the data with the median value and the vertical lines show the total extent of the dataset.

3. METHOD

3.1. Target subsetting

Unfortunately, the respective target area where ground-based measurements were taken was only imaged by one CHRIS FZA (-33.66°). However, using a land use map of 2006 helped in finding other Triticale fields which were observed by the available three CHRIS viewing angles. In total 4 other fields consisting of Triticale were determined. However, two of them (field 1 and field 2) could not be clearly identified on the land use map, but showed very similar spectral characteristics in the CHRIS image. Fig. 5 indicates a spectral comparison of the 4 fields under question in relation to the actual Triticale field where ground sampling took place.

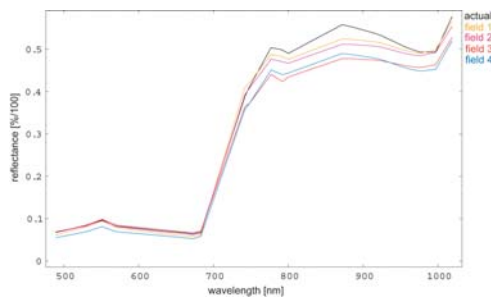


Figure 5. CHRIS spectral signature of selected Triticale fields.

Triticale was knowingly grown on field 3 and field 4 although the reflectances show a remarkable offset in the near infrared range (NIR). Additionally, the spectral signature of field 4 coincides worst in the visual spectral range (VIS) and was consequently dropped. With regard to VI's analysis a good spectral agreement over the respective wavelength region is preferential. Field 1 and field 3 fulfill this criterion. However, field 1 is not proven to be Triticale. Because of that and in order to level out possible errors, an average of the two was calculated for every FZA and used for further investigation. The spectral average of the two fields is shown in Fig. 6 in relation to the actual field.

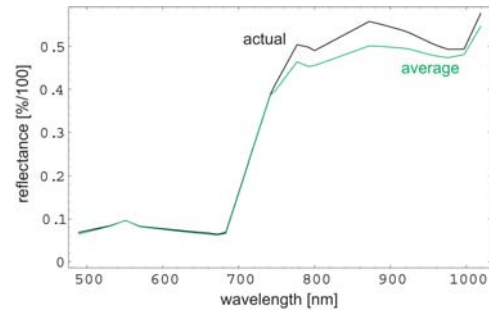


Figure 6. Spectral comparison of the averaged signal to the signal of the actual Triticale field.

3.2. Hemispherical conical reflectance factor

In total 66 target measurements and 6 reference measurements are performed with FIGOS. The HCRF is then calculated for every view angle by normalizing all spectrodirectional measurement $L_{\text{reflected}}^{\text{target}}$ of one azimuth plane with the respective reference measurement, $I_{\text{reflected, nadir}}^{\text{reference}}$, obtained at nadir. Since the Spectralon panel is often used in the field and its lambertian properties are degrading over time, a correction factor $R_{\text{reference}}$ is used in Eq. 1.

$$\text{HCRF} = \frac{L_{\text{reflected}}^{\text{target}}}{I_{\text{reflected, nadir}}^{\text{reference}}} * R_{\text{reference}} \quad (1)$$

Following this procedure provides the advantage of partly assessing the changing atmospheric influence during the total measurement time of 20 to 30 minutes per hemisphere. The HCRF is subsequently interpolated over the view angles to determine the corresponding reflectance values at CHRIS FZA's. Fig. 7 shows the CHRIS path projected on the HCRF at a wavelength of 550 nm with.

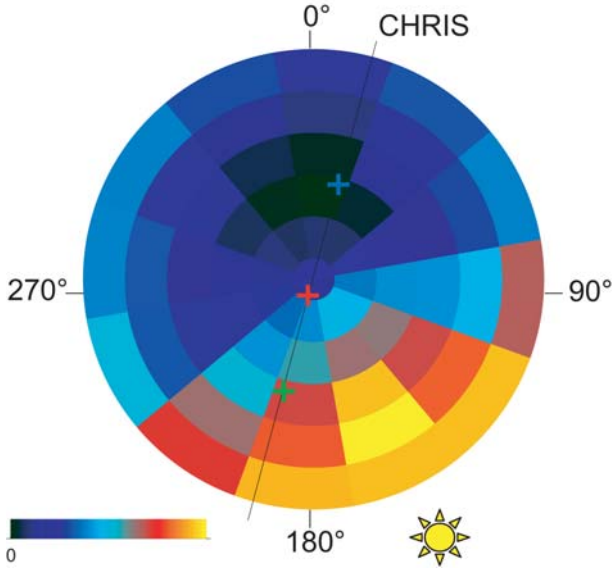


Figure 7. CHRIS flight path projected on HCRF values of FIGOS at 550nm.

Further analysis of directional effects is done by referring to the CHRIS flight path as the CHRIS azimuth plane.

3.3. Vegetation indices determination

In a first step FIGOS reflectances needed to be spectrally convoluted with regard to CHRIS center wavelength and bandwidths. Subsequently, goniometric data were interpolated over all view angles for the respective wavelengths used for the VI determination. Directional analysis is then performed for the narrowband NDVI calculated from HCRF data. The NDVI is determined according to Eq. 2 using CHRIS band 7 (661nm) and band 17 (742nm) for RED and NIR, respectively.

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \quad (2)$$

As a second VI the photochemical reflectance index PRI was chosen. The PRI belongs to the narrowband greenness indices and gives a measure of the efficiency with which vegetation is able to use incident light for photosynthesis [9]. Calculation of the PRI is performed according to Eq. 3 using CHRIS band 3 (530) and band 4 (570nm), respectively.

$$NDVI = \frac{\rho_{530} - \rho_{570}}{\rho_{530} + \rho_{570}} \quad (3)$$

Generally, indices were selected for wavelengths fitting within or closely approaching the centerbands of CHRIS mode 5.

Directional analysis was performed for both the total goniometric view angle set and for the respective azimuth plane corresponding to real CHRIS FZA's.

4. RESULTS

4.1. HCRF comparison

Spectrodirectional reflectances of FIGOS tend to show comparable values for all CHRIS FZA's. Differences are most pronounced for forward scattering reflectances where cast shadow is more dominant on the target area. This is particularly the case for FIGOS which is operating with a 3° FOV and thus observes more shadowed areas within the Triticale canopy. Highest reflectance values were measured in the backward scattering range and lowest values in the forward scattering range.

A spectrodirectional comparison between the HCRF of CHRIS data and FIGOS data is shown in Fig. 8.

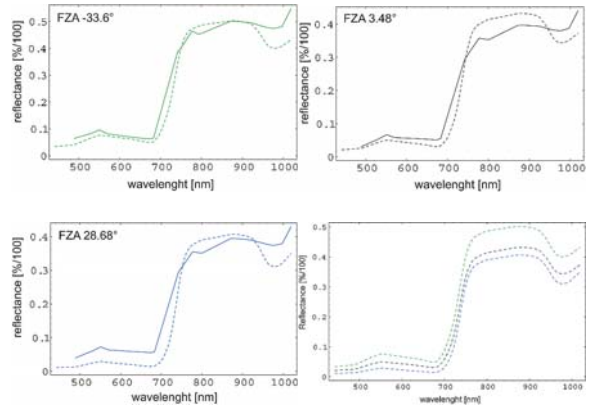


Figure 8. Spectrodirectional comparison of CHRIS HCRF (solid) and FIGOS HCRF (dashed) for the respective CHRIS FZA's.

4.2. Directional VI's

The NDVI and PRI are analysed over the whole hemisphere for FIGOS. For both VI's a directional dependency can be seen.

For the NDVI a maximum anisotropy is reached in the forward scattering region (illumination zenith angle was 29.4° for the respective hemisphere). The sun azimuth change of 13.9° during the measurement time seems to influence the shape and orientation of the maximum NDVI values. Maximum directional NDVI may be explained by observing cast shadow which decreases the RED reflectance and affects NIR reflectances only minimal. NIR reflectances are generally more affected by multiple scattering effects within the canopy. However, in the CHRIS azimuth plane a reasonable agreement with CHRIS NDVI is only obtained for backward scattering data. Fig. 9 shows the NDVI distribution over all view angles observed with the goniometer (right) and in the CHRIS azimuth plane (left).

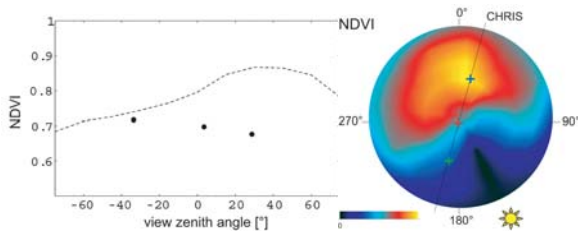


Figure 9. Left: NDVI distribution of three CHRIS FZA's (points) and FIGOS (dashed line) along the CHRIS azimuth plane. Right: Hemispherical distribution of FIGOS NDVI.

Part of the disagreement of CHRIS NDVI values for nadir and forward viewing directions might be related to specific sensor characteristics and target scale issues. FIGOS is currently operated with a 3° FOV which results in a GIFOV of 10cm at nadir. Therefore the FIGOS sensor signal is more affected by the small scale distribution of illuminated and shadowed areas within the canopy than this is the case for the CHRIS sensor. Consequently, the NDVI agreement of CHRIS and FIGOS is better for the backscattering view angle (less shadow).

The distribution of PRI values retrieved from FIGOS HCRF shows a similar but reverse pattern to the reflectance distribution (see Fig. 7) with maximum PRI's at minimum reflectances. CHRIS PRI values reasonably agree for the nadir and the forward scattering directions. The offset for the backward scattering PRI is related to the fact that a higher reflectance value is registered for CHRIS band 3 (530nm) than for band 4 (570nm), respectively, leading to a positive PRI value. A possible explanation might be a poor atmospheric correction due to the chosen aerosol model. Fig. 10 shows the respective PRI values for goniometric and CHRIS data.

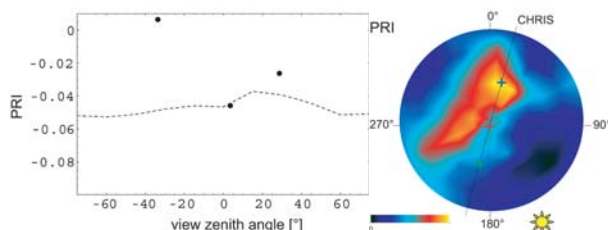


Figure 10. Left: PRI distribution of the three CHRIS FZA's (points) and FIGOS (dashed line) along the CHRIS azimuth plane. Right: Hemispherical distribution of FIGOS PRI.

5. CONCLUSIONS & OUTLOOK

The presented study showed a spectrodirectional comparison between spaceborne CHRIS PROBA data and goniometric data acquired with FIGOS. Although ground-based data were collected two days later but under similar atmospheric and illumination conditions, spectral HCRF comparison showed a good overall

agreement for the respective view zenith angles. However, forward scattering reflectances seem to be more sensitive to target heterogeneity and associated canopy element scales, which both strongly affect the distribution of illuminated and shadowed target areas. Such factors are more dominant in the visible range of the spectrum and may lead to errors when data of sensors with different physical characteristics (e.g. FOV) are compared. For the backward scattering region such effects seem to be of minor importance and a good agreement between NDVI values of CHRIS and FIGOS was obtained. However, having only three CHRIS view angles available was strongly limiting directional NDVI analysis. The same is true for PRI analysis. Additionally, for the PRI special attention has to be paid to the atmospheric correction in the visible spectral range and various aerosol models should be tested for good results. The combination of simultaneously acquired multiangular spaceborne and ground-based data not only supports the assessment of directional effects of VI's at various scales. It also bears the potential of improved directional calibration instead of using only nadir-view ground-truth measurements.

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REFERENCES

1. Verrelst, J., Koetz, B., Kneubühler, M. and Schaepman, M., (2006). Directional Sensitivity Analysis of Vegetation Indices from Multiangular CHRIS/PROBA Data. In Proc. ISPRS Mid-term Symposium 2006, Enschede, Netherlands.
2. Huber, S., Kneubühler, M., Koetz, B., Schopfer, J.T., Zimmermann, N.E. and Itten, K.I., (2007). Estimating Nitrogen Concentration from Directional CHRIS/PROBA Data. In Proc. 10th International Symposium on Physical Measurements and Signatures in Remote Sensing ISPMRS, Davos, Switzerland.
3. Strub, G., Beisl, U., Schaepman, M., Schlaepfer, D., Dickerhof, C. and Itten, K., (2002). Evaluation of diurnal hyperspectral HDRF data acquired with the RSL field goniometer during the DAISEX'99 campaign. *Journal of Photogrammetry and Remote Sensing* **57**(3), pp. 184-193.
4. Huete, A.R., Hua, G., Qi, J., Chehbouni, A. and van Leeuwen, W.J.D., (1992). Normalization of multidirectional red and NIR reflectances with the SAVI. *Remote Sensing of Environment* **41**(2-3), pp. 143-154.
5. Hu, B., Lucht, W., Strahler, A.H., Barker Schaaf, C. and Smith, M., (2000). Surface Albedos and Angle-Corrected NDVI from AVHRR Observations of

South America. *Remote Sensing of Environment* **71**(2), pp. 119-132.

6. Qi, J., Moran, M.S., Cabot, F. and Dedieu, G., (1995). Normalization of sun/view angle effects using spectral albedo-based vegetation indices. *Remote Sensing of Environment* **52**(3), pp. 207-217.
7. Gemmell, F. and McDonald, A.J., (2000). View Zenith Angle Effects on the Forest Information Content of Three Spectral Indices. *Remote Sensing of Environment* **72**(2), pp. 139-158.
8. Tucker, C.J., (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment* **8**(2), pp. 127-150.
9. Gamon, J.A., Serrano, L. and Surfus, J.S., (1997). The photochemical reflectance index: an optical indicator of photosynthetic radiation use efficiency across species, functional types, and nutrient levels. *Oecologia* **112**(4), pp. 492-501.
10. Schneider, T., Schopfer, J., Oppelt, N., Dorigo, W., Vreeling, W. and Gege, P., (2007). GonioExp06 - A Field Goniometer Intercomparison Campaign, in Support of Physical Model Inversion and Upscaling Methods for Hyperspectral, Multispectral RS Data. In Proc. Envisat Symposium, in press., ESA, Montreux, Switzerland.
11. Barnsley, M.J., Settle, J.J., Cutter, M.A., Lobb, D.R. and Teston, F., (2004). The PROBA/CHRIS mission: a low-cost smallsat for hyperspectral multiangle observations of the Earth surface and atmosphere. *IEEE Transactions on Geoscience and Remote Sensing* **42**(7), pp. 1512-1520.
12. Toutin, T., (2004). Review article: Geometric processing of remote sensing images: models, algorithms and methods. *International Journal of Remote Sensing* **25**(10), pp. 1893-1924.
13. Kneubühler, M., Koetz, B., Richter, R., Schaepman, M. and Itten, K., (2005). Geometric and Radiometric Pre-processing of CHRIS/PROBA Data over Mountainous Terrain. In Proc. 3rd CHRIS/PROBA Workshop, Frascati (I), SP-593, ESA Publications Division, Noordwijk, NL.
14. Schlöpfer, D., Nieke, J. and Itten, K.I., (2007). Spatial PSF Nonuniformity Effects in Airborne Pushbroom Imaging Spectrometry Data. *Geoscience and Remote Sensing, IEEE Transactions on* **45**(2), pp. 458-468.
15. Richter, R., (1998). Correction of Satellite Imagery Over Mountainous Terrain. *Applied Optics* **37**(18), pp. 4004-4015.
16. Schopfer, J., Dangel, S., Kneubühler, M. and Itten, K., (2007). Dual Field-of-View Goniometer System FIGOS. In Proc. ISPMSRS, in print, Davos, Switzerland.
17. Analytical Spectral Devices Inc., (1999). Technical Guide, 4th Ed., Analytical Spectral Devices, Inc., Boulder, Colorado, USA.